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MULTI-SENSOR FEATURE LEVEL FUSION

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ABSTRACT

The Multi-Sensor Feature Level Fusion (MSFLF) program is intended to improve automatic target recognition (ATR) performance by the use of multi-sensor feature techniques. MSFLF algorithms are evaluated using multi-sensor (8–12m FLIR, 94GHz MMW radar and 10.6m CO_2 laser radar) data and imagery. This report gives the results of target detection and identification using the MSFLF training IR imagery. A set of image quality measures are defined and computed over the imagery. These quality measures suggest that performance should be better for the training imagery than for the test imagery. An overview of the FLIR and MMW radar algorithms, detailed descriptions of the IR target detection and identification algorithms are presented in a seperate proprietary report.

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1.0 Introduction

The FLIR/MMW radar target identification algorithms have been applied to three different data sets; Phase 1, Vision 1 Training, and Vision 1 Testing. The Phase 1 and Vision 1 Training FLIR imagery was used with simulated MMW radar range data. The limited amount of multi-sensor data precluded true FLIR/MMW radar sensor fusion target identification for these data sets. These FLIR data sets were utilized in the development of the target detection and identification algorithms. Target identification results using the Phase 1 and Vision 1 Training FLIR imagery are presented in this report. The Vision 1 Test data contains both FLIR imagery and MMW radar data. The target detection and identification performance for the Vision 1 Test dataset is not presented in this report since it was scored by the government.

Target identification has been performed at two different levels. One level performs identification given ideal locations of the target. The true targets are ground truthed with boxes placed on the FLIR images around the targets during a manual operation. This ideal detection gives an indication of the best performance of the identification process. The second level uses the detection algorithm to detect and place boxes around the estimated target locations. This method results in missed targets, false alarms, and partly miss–placed boxes.

The identification process identifies the target as a specific type, *e.g.* M115 APC. The recognition process is a grouping of targets into three groups; tank, APC, and truck. The classification process is also grouping of targets but only into two classes; tracked and wheeled. Unlike the single sensor cases were classification and recognition are performed, the FLIR/MMW radar algorithm performs target identification only. Recognition and classification are a grouping of the results of the identification process.

The characteristics of the FLIR imagery are critical to target detection and identification performance. Image quality measures (QM) have been defined which measure the clutter and target signal level in the region around the target. They use the target's pixel location box defined in the ground truthing of the FLIR imagery. The QM's are intended to estimate expected detection and identification algorithm performance. The statistics of these QM's provide relative target-to-clutter between different data sets and are correlated to subsequent target detection and identification performance.

2.0 Target Detection and Identification Results

2.1 Phase 1 FLIR Imagery Results

The Phase 1 FLIR imagery field-of-view (fov) is 3.43° x 2.58° for the narrow fov and 10.32° x 7.74° for the wide fov. The target range varies from 500m to 1700m, most are near 1000m, with up to four targets in the wide fov. The target location varied from in the open with little clutter, to along the tree line with considerable clutter. The Phase 1 FLIR imagery contains only five target types:

1. M151 Jeep
2. M35 Truck
3. M113 APC
4. M60 Tank
5. M551 Tank

The M60 tank is represented by both the long barrel M60A1 and the short barrel M60A2. Two different trucks are present in the Phase 1 imagery but a single M35 model was used.

Table 2.1 presents the results of target detection and identification applied to Phase 1 FLIR imagery, both narrow and wide fov imagery. The results presented for Phase 1 are for the older version of the spoke filter detection algorithm. The recognition and identification percentages are conditioned on the occurance of target detection. Since five target models are used the expected random identification is 20%. The expected random target recognition is 33% since their are three recognition groups; tank, APC and truck.

Table 2.1 Phase 1 Imagery Target Detection, False Alarm, Recognition, and Identification Performance

FOV	AREA	IMAGES	TARGETS	DETECTIONS		FALSE ALARMS			REC	ID
	sq deg						/image	/sq deg	cond	cond
NARROW	8.85	449	834	497	60%	114	0.25	0.10	58%	47%
WIDE	79.88	319	659	276	42%	12	0.04	0.02	42%	31%
Expected random results									33%	20%

The identification performance was evaluated using Phase 1 FLIR imagery under ideal detection. This allows for investigation of the identification performance of all the targets present in the imagery, not just those detected by the specific detection algorithm. Using ideal detection boxes the results are given by Table 2.2. It is clear that the identification increases by 9 and 5% points for the narrow and wide fov cases using ideal detection. This is even more significant since the additional targets (825 vs 497 narrow fov) which were not detected by the detection algorithm are in general of poorer quality, and are included for identification under the ideal detection case of Table 2.2.

Table 2.2 Phase 1 Target Recognition and Identification Performance with Ideal Detection

FOV	IMAGES	TARGETS	REC	ID
NARROW	442	825	63%	56%
WIDE	450	837	49%	36%
Expected random results			33%	20%

The results presented in Tables 2.1 and 2.2 were computed at different times consequently they do not contain exactly the same images. Seven of the narrow fov images were discarded due to extreme poor quality. One hundred thirty-one additional wide fov images were available when the ideal identification performance of Table 2.2 was computed.

In order to further investigate the identification performance the Phase 1 narrow fov results are divided into different groups of data. Table 2.3 presents these results for the specific target types of the different groups of imagery. Some of the imagery is high clutter while the others have targets which partially obscure other targets. The last group has a few camouflaged M60 tanks.

Table 2.3 Phase 1 Target Recognition and Identification Performance by Groups with Ideal Detection (Narrow FOV)

IMAGE FILES	COMMENTS	TARGETS	IDENTIFICATION						TOTAL	
			TANK		APC	TRUCK	JEEP	TANK		
			M60	M551	M113	M35	M151	REC	REC	ID
note A	clutter	141	82%	-	69%	-	0	92%	84%	77%
dd0271,3	tree line	77	77%	54%	-	0	0	90%	70%	56%
df0871	500m range	26	56%	-	-	90%	-	62%	73%	69%
df1271	3 tgt/image	81	59%	-	52%	56%	-	85%	64%	56%
df1572	P.O.	127	-	20%	74%	-	9%	42%	44%	36%
note B	low contrast	278	50%	19%	76%	36%	-	53%	50%	47%
df2371,2-	P.O.	86	-	-	89%	58%	-	-	72%	72%
df2372+	camouflage	8	63%	-	-	-	-	63%	63%	63%
TOTAL		824	74%	23%	74%	47%	6%	73%	63%	56%
TRUE TARGETS		824	208	123	246	194	54	331	824	824
ID AS TYPE		824	278	100	302	106	26	378	-	-
CORRECT		824	154	28	182	91	3	243	519	458

P.O. = Some of the targets are partially obscured, two or three targets per image.
camouflage = One of the two M60 tank targets per image is camouflaged.
Of the 824 targets, 13 (2%) were incorrectly identified as clutter.
note A = dc2571,dc2572,dc2672,dc2673,df0571,df1071
note B = df1971,df1972,df2271,df2272,df2471

As is evident from Table 2.3, identification performance varies from 36% to 77% (56% average), while recognition varies from 44% to 84% over the 8 groups of imagery. The M151 jeep was the most difficult to identify. This is in part due to its small size but also most of the jeep images are in the high clutter environment. The best identification performance (74%) is of the M60 Tank and M113 APC.

The correct identification and miss-identification between target types is illustrated in the confusion matrix of Table 2.4. The columns of the matrix list the number of targets of each type which are identified as the target type of the column heading. For example, 278 targets were identified as M60 tanks, 124 of these identifications were incorrect ('BAD') and 154 were correctly identified. The correct identification falls along the matrix diagonal. Summing across each row gives the true number of each target type. A total of 13 targets are incorrectly identified as clutter (CLUT).

Table 2.4 Phase 1 Target Confusion Matrix (Ideal Detection, Narrow FOV)

	IDENTIFICATION TARGET TYPE					
		TANK		APC	TRUCK	
TRUE	CLUT	M60	M551	M113	M35	M151
M60	7	*154*	25	11	8	3
M551	0	36	*28*	57	2	0
M113	0	24	21	*182*	5	14
M35	1	45	19	32	*91*	6
M151	5	19	7	20	0	*3*
TOTAL	13	278	100	302	106	26
BAD	13	124	72	120	15	23

The percentage correct identification and miss-identification between target types are illustrated in the confusion matrix of Table 2.5. This table is based on the numbers presented in Table 2.4. The identification numbers are divided by the number of true targets of each type. For example reading across the M60 row, 74% of the true M60 targets are correctly identified, with the most common (12%) miss identification being the M551 tank. The bottom row of the table ('BAD') presents percentage of incorrect identifications for the specific target type of the column heading. For example, 100 targets are identified as M551 of these 28 are correct, giving 72% 'BAD' identification of those identified as an M551 tank. This indicates that very few of the targets are incorrectly identified as the M35 truck. The last row ('BIAS') indicates the percentage of targets identified as the type relative to the true number of that type of target.

Table 2.5 Phase 1 Percentage Target Confusion Matrix (Ideal Detection, Narrow FOV)

	IDENTIFICATION TARGET TYPE					
		TANK		APC	TRUCK	
TRUE	CLUT	M60	M551	M113	M35	M151
M60	3%	*74%*	12%	5%	4%	1%
M551	0	29%	*23%*	46%	2%	0
M113	0	10%	9%	*74%*	2%	6%
M35	1%	23%	10%	16%	*47%*	3%
M151	9%	35%	13%	37%	0	*6%*
BAD	100%	45%	72%	40%	14%	88%
BIAS	-	134%	81%	123%	55%	48%

The following lists some of the identification relationships between the different target types.

1. The M60 tank and M113 APC targets are identified correctly 74% of the time with little confusion (<12%) with other target types.
2. Of the targets identified as M60 tanks 55% are correct.
3. Of the targets identified as M113 APCs 60% are correct.
4. The identification bias is toward the M60 tank and M113 APC, with the M35 truck and M151 jeep least likely.
5. While the M35 truck and the M151 jeep are correctly identified only 47% and 6% of the time, other targets are seldom miss-identified as either.
6. Of the targets identified as M151 jeeps only 12% are correct.
7. Of the targets identified as M35 trucks 86% are correct.
8. The M151 jeep and M551 tank are the only target types which are less frequently identified as the correct target type versus some other target type. Both the M551 tank and M151 jeep are more frequently identified as the M113 APC.

The wide fov confusion matrix is presented in Table 2.6. The M60 tank is the most common target (217 occurrences) but even more targets were identified as M60's (366) of these 212 are incorrect. The least common target is the M151 jeep (53 occurrences) but only 16 of the targets are identified as M151's. One M35 target is incorrectly identified as clutter (CLUT).

Table 2.6 Phase 1 Target Confusion Matrix (Ideal Detection, Wide FOV)

	IDENTIFICATION TARGET TYPE					
		TANK		APC	TRUCK	
TRUE	CLUT	M60	M551	M113	M35	M151
M60	0	*154*	24	11	23	5
M551	0	49	*18*	12	8	2
M113	0	71	33	*33*	14	1
M35	1	71	36	15	*24*	0
M151	0	21	8	10	6	*8*
TOTAL	1	366	119	81	75	16
TRUE	0	217	89	152	147	53
BAD	1	212	101	48	51	8

2.2 Vision 1 Training FLIR Imagery Results

The Vision 1 training imagery consists of FLIR images of a single target at a range of about 1000km. The imagery is taken with the target rotated at 5° increments. It is generally a low clutter environment with most of the differences in image quality resulting from the weather conditions, vehicle operation and time of day. The initial Vision 1 data contains the same targets as Phase 1 data, with the exception of the M151 jeep. Later Vision 1 data included additional target types, in total nine targets are included.

1. M35 Truck
2. M113 APC
3. M60 Main Battle Tank, both M60A1 and M60A2
4. M551 Sheridan Light Tank
5. M1 Abrams Main Battle Tank
6. M2 Bradley Infantry Fighting Vehicle
7. M110 Self-propelled Howitzer
8. M163 Vulcan Air Defense System
9. M578 Light Armored Recovery Vehicle

Table 2.7 presents the results of target detection and identification over the Vision 1 Training imagery, both narrow and wide fov. The spoke filter algorithm which performs detection has been modified since these results were computed. The results presented for Vision 1 Training are for the older version of the detection algorithm. The recognition and identification percentages are conditional given that a detection occurs. Since ten target models are used, including the two variations of the M60, the expected random identification is 10%. The set A data consists of the initial five targets (M60A1, M60A2, M551, M113, and M35). The set B data consists of the five targets; M1, M2, M110, M163, and M578. The initial set of imagery (set A) was ran using five target models while the second set of imagery (set B) was ran using the total of ten target models. The combined set of imagery (sets A&B) was later ran with the total set of ten target models. As should be expected the results are better when only five target models are required. The wide fov set B was not ran since narrow fov was of primary interest.

Table 2.7 Vision 1 Training Target Detection, False Alarm, Recognition, and Identification Performance

FOV	SET	AREA	MODELS	TGTS	DETECTIONS		FALSE ALARMS			REC	IDENTIFICATION	
		sq deg						/image	/sq deg	cond	conditional	
NARROW	A	3.35	5	210	201	96%	68	0.32	0.18	68%	63%	
NARROW	B	2.61	10	314	281	90%	35	0.11	0.07	51%		19%
NARROW	A&B	2.91	10	524	482	92%	103	0.20	0.09	58%		37%
WIDE	A	29.63	5	211	160	76%	20	0.09	0.04	44%	41%	
Expected random results										33%	20%	10%

Set A contains inital five targets (M60A1, M60A2, M551, M113, M35).
Set B contains final five targets (M1, M2, M110, M163, and M578).

The identification performance was evaluated using Vision 1 Training FLIR imagery under ideal detection. This allows for investigation of the identification performance of all the targets present in the imagery, not just those detected by the specific detection algorithm. Using ideal detection boxes the results are given by Table 2.8. Identification using ideal detection increases by 7% points (37% to 44%) for narrow fov with ten target models (sets A&B) but decreases 12% points (41% to 29%) for the wide fov case. Performance was improved using the total imagery set (A&B) by minor modification of the target models and reduction in the number of sensed image edge pixels considered. The identification improved from 35% to 44%.

Table 2.8 Vision 1 Target Recognition and Identification Performance with Ideal Detection

FOV	SET	MODELS	TARGETS	REC	ID
NARROW	A	5	210	71%	67%
NARROW	B	5	314	66%	47%
NARROW	A	10	210	55%	43%
NARROW	B	10	314	56%	32%
NARROW	A&B	10	524	55%	35%
Improved performance (A&B, 10 Models)*				63%	44%
WIDE	A	5	211	32%	29%
WIDE	B	10	318	44%	14%
Expected random results				33%	20% 10%
* Performance was improved by modification of the target models and reduction in the number of edge pixels.					

The target identification performance for each of the nine target types, the M60A1 and A2 are grouped together, using the ideal detections is presented in Table 2.9. There are a total of 524 targets of which (229) 44% are correctly identified. This 44% correct identification is the average over all the different target types. The poorest identification (10%) is for the M551 tank, while the best (84%) is for the M113 APC. The three groups used for target recognition are somewhat arbitrary.

Table 2.9 Vision 1 Target Type Identification using Ideal Detection

	TANK CLASS						APC CLASS		TRUCK
	M551	M60	M1	M2	M110	M578	M113	M163	M35
NUMBER IDENTIFIED AS THIS TYPE	26	75	55	80	33	29	112	55	59
NUMBER TRUE TARGETS OF THIS TYPE	10	63	69	115	72	7	85	51	52
NUMBER CORRECT IDENTIFICATION	1	29	26	46	14	4	71	14	24
% CORRECT IDENTIFICATION	10%	46%	38%	40%	19%	57%	84%	27%	46%
NUMBER TRUE TARGETS OF THIS CLASS	336						136		52
NUMBER CORRECT RECOGNITION	254						103		24
% CORRECT RECOGNITION	76%						76%		46%

The correct identification and miss-identification between target types is illustrated in the confusion matrix of Table 2.10. The columns of the matrix list the number of targets of each type which are identified as the target type of the column heading. For example, 75 targets were identified as M60 tanks, 46 of these identifications were incorrect ('BAD') and 29 were correctly identified. The largest number of the incorrectly identified as M60 tanks (19) are in truth M110's. The correct identification falls along the matrix diagonal. Summing across each row gives the true number of each target type.

Table 2.10 Vision 1 Target Confusion Matrix (Ideal Detection, Narrow FOV)

	IDENTIFICATION TARGET TYPE								
	TANK CLASS						APC CLASS		TRUCK
TRUE	M551	M60	M1	M2	M110	M578	M113	M163	M35
M551	*1*	1	3	2	0	0	0	1	2
M60	2	*29*	3	4	7	1	2	10	5
M1	2	8	*26*	6	3	2	6	8	8
M2	10	7	15	*46*	8	10	5	4	10
M110	6	19	6	6	*14*	2	8	5	6
M578	0	0	0	1	0	*4*	1	1	0
M113	2	3	1	0	0	2	*71*	3	3
M163	3	6	1	9	0	2	15	*14*	1
M35	0	2	0	6	1	6	4	9	*24*
TOTAL	26	75	55	80	33	29	112	55	59
BAD	25	46	29	34	19	25	41	41	35

The percentage correct identification and miss-identification between target types is illustrated in the confusion matrix of Table 2.11. This table is based on the numbers presented in Table 2.10. The identification numbers are divided by the number of true targets of each type. For example reading across the M60 row, 46% of the true M60 targets are correctly identified, with the most common (16%) miss-identification being the M163. The bottom row of the table ('BAD') presents percentage of incorrect identifications for the specific target type of the column heading. For example, 26 targets are identified as M551 of these only 1 is correct, giving 96% 'BAD' identification of those identified as M551 tank.

Table 2.11 Vision 1 Percentage Target Confu:ion Matrix (Ideal Detection, Narrow FOV)

	IDENTIFICATION TARGET TYPE								
	TANK CLASS						APC CLASS		TRUCK
TRUE	M551	M60	M1	M2	M110	M578	M113	M163	M35
M551	***10%***	10%	30%	20%	0	0	0	10%	20%
M60	3%	***46%***	5%	6%	11%	2%	3%	16%	8%
M1	3%	12%	***38%***	9%	4%	3%	9%	12%	12%
M2	9%	6%	13%	***40%***	7%	9%	4%	3%	9%
M110	8%	26%	8%	8%	***19%***	3%	11%	7%	8%
M578	0	0	0	14%	0	***57%***	14%	14%	0
M113	2%	4%	1%	0	0	2%	***84%***	4%	4%
M163	6%	12%	2%	18%	0	4%	29%	***27%***	2%
M35	0	4%	0	12%	2%	12%	8%	17%	***46%***
BAD	96%	61%	53%	43%	58%	86%	37%	75%	59%
BIAS	260%	119%	80%	70%	46%	414%	132%	108%	113%

As is evident from the confusion matrices, the best identification performance is for the M113 APC, with 84% correct identification and only 37% miss—identified as the M113. The M163 is an air defense gun mounted on an M113 chassis, consequently 29% of the M163 are miss-identified as M113's. Also the M2 front or rear view is very much like the 180° inverse of the M163 resulting in 18% miss-identification of the M163 as the M2. In all cases except for the M551 tank, M110 gun, and M163 ˙r defense unit the correct target is the most common identification.

3.0 FLIR Image Quality Measures

3.1 Definition of Quality Measures

Image quality measures (QM) estimate the clutter and target signal level in the region around the target, using the pixel location box defined in the ground truthing of the FLIR imagery. A box region expanded by one-half of the ground truthed target size on each of the sides around the target is used as the background. The ground truthed target box contains the region used for the target statistics. The target excludes a border of 2 pixels which are not counted as either target or background. The top one-third of the ground truth box has only a maximum of 2m at the center used as the target, the rest is not counted as target or background. These border regions are defined to minimize counting non-target background within the target statistics.

Four QM's are defined. The first three QM's are target-to-background contrast measures. The fourth QM measures the difference in the intensity distributions between target and background. The first QM is the difference between target average intensity (A_T) and background average intensity (A_B) normalized by the image intensity standard deviation within and around the target and scaled by the square root of the number of target pixels ($\sqrt{N_T}$).

$$QM_1 = \sqrt{N_T}\frac{|A_T - A_B|}{\sqrt{\sigma_T^2 + \sigma_B^2}}$$

Where σ_T^2 is the variance of intensity within the target region and σ_B^2 is the variance within the background region.

The second QM includes the difference in intensity variation within the target and background regions. This attempts to account for different textures between target and background.

$$QM_2 = \sqrt{N_T}\frac{|A_T - A_B| + |\sigma_T - \sigma_B|}{\sqrt{\sigma_T^2 + \sigma_B^2}}$$

The third QM is similar to the first except order statistics are used. The QM is based upon intensity percentile locations on a histogram of the target and background intensity distributions.

$$QM_3 = \sqrt{N_T}\frac{|P50_T - P50_B|}{\sqrt{(P80_T - P20_T)^2 + (P80_B - P20_B)^2}}$$

Where P20, P50, and P80 are the 20%, 50% (median), and 80% intensity levels of the target and background regions.

The fourth QM is based upon the difference between the histograms of the target and background intensity distributions. The QM value indicates the commonality between the target and background IR intensity distributions.

$$QM_4 = \frac{1}{n}\sum_{i=1}^{n} M_i$$

Where M_i is the i^{th} peak of the minimum between the target and background intensity histograms, n is 10 for the results presented.

3.2 FLIR Image Quality Measure Results

The QM's computed over the narrow fov imagery are presented in Table 3.1. The first three QM's increase with improved image quality, since they are contrast measures. The Fourth QM decreases with improved image quality, since it measures the level of commonality between the target and background regions. The Vision 1 Training imagery is divided into sets A and B . The A set corresponds to the initial set of five targets (M60A1, M60a2, M35, M113, and M551) and the B set corresponds to the second set of five targets (M1, M2, M163, M578, and M110). The Vision 1 Test imagery consists of three images which cover the scene; the left, center, and right hand images. Each of the QM's were not computed over all of the data due to time limitations and limited computer storage, resulting in blanks in some of the columns of Table 3.1.

Table 3.1 FLIR Imagery Quality Measures Are an Indication of Expected Detection and Identification Performance.

DATASETS	NUMBER OF TARGETS	CONTRAST MEASURES						COMMONALITY MEASURE	
		QM1		QM2		QM3		QM4	
		mean	sigma	mean	sigma	mean	sigma	mean	sigma
PHASE 1	838	16.7	8.3						
VISION 1 TRAIN A	210	13.9	7.6			9.2	7.5	5.8	4.0
VISION 1 TRAIN B	314	17.9	6.6			10.3	5.0	6.3	3.1
VISION 1 TRAIN A & B	524	16.3	7.0			9.9	6.0	6.1	4.2
VISION 1 TEST LEFT	104	14.0	6.4	20.4	6.0				
VISION 1 TEST CENTER	152	8.4	5.0	14.2	5.9				
VISION 1 TEST RIGHT	145	8.1	4.7	12.7	5.7				
VISION 1 TEST	401	12.0	7.2	15.2	6.7	6.7	4.5	5.5	3.7

It is evident that on average the Phase 1 and Vision 1 Training imagery target contrast is better than for the Vision 1 Test imagery. The left side of the scene for the Vision 1 Test has a better target-background contrast than does the center or right side. This is easily verified by visual examination of the imagery. The center and right side have greater levels of bright clutter due to cleared road surfaces.